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TITLE: TRANSIENT PHENOMENA ON ZT-40

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TRANSIENT PHENOMENA ON ZT-40*

by

A. R. Jacobson and C. J. Buchenauer

INTRODUCTION

This paper examines two aspects of fluctuations in the ZT-40 reversed field pinch. First, the polarization of the magnetic fluctuations in the outer (vacuum) region is discussed. This in turn provides information on the wavevectors associated with the turbulence. The results provide some clues about the location (in minor radius) of the singular surfaces which are customarily associated with fluctuations. Second, the density fluctuations are studied using a multichord interferometer. We report on the spatial distribution (in major radius) of the chord-averaged fluctuations.

POLARIZATION OF MAGNETIC FLUCTUATIONS AT THE WALL

External magnetic probes have been used to study the time behavior of the magnetic fields close to the shell ($r = r_w = 21.8$ cm), outside the ceramic liner. Both B_θ and B_ϕ are measured simultaneously at two poloidal locations (separated by $\Delta\Theta = \pi$), that is, near the inside and outside in terms of major radius. The common-mode and differential-mode fields are, respectively:

$$\vec{B}^{(0)} \equiv \frac{1}{2}\left\{\vec{B}^{\text{inside}} + \vec{B}^{\text{outside}}\right\}$$

$$\vec{B}^{(1)} \equiv \frac{1}{2}\left\{\vec{B}^{\text{inside}} - \vec{B}^{\text{outside}}\right\}$$

We reexpress the differential-mode (mainly fluctuating) field in terms of components parallel and perpendicular to the instantaneous common-mode (mainly equilibrium) field, via:

$$\vec{B}_\parallel^{(1)} \equiv \frac{\vec{B}^{(0)} \cdot \vec{B}^{(1)}}{|\vec{B}^{(0)}|}\,\hat{e}_\parallel \;;\quad \vec{B}_\perp^{(1)} \equiv \frac{\vec{B}^{(0)} \times \vec{B}^{(1)}}{|\vec{B}^{(0)}|}$$

(Note that the "parallel" and "perpendicular" coordinate axes are constantly shifting with the orientation of $\vec{B}^{(0)}$ in the θ-ϕ surface.) We wish to study the polarization ratio, i.e., $B_\parallel^{(1)}/B_\perp^{(1)}$. To exclude the effects of slow offsets, the ratio will actually be determined in terms of the derivatives, i.e., $\dot{B}_\parallel^{(1)}/\dot{B}_\perp^{(1)}$; the two definitions coincide for a single frequency mode. A turbu-

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lence weighting factor $[\dot{B}_\perp^{(1)}]^2$ is used, so that for any given discharge, we calculate

$$\int_\tau \frac{\dot{B}_\parallel^{(1)}}{\dot{B}_\perp^{(1)}} [\dot{B}_\perp^{(1)}]^2 \, dt \Big/ \int_\tau [\dot{B}_\perp^{(1)}]^2 \, dt$$

The averaging time τ is a 50 μs interval, centered at peak θ, during which both θ and F are sensibly constant.

The polarization ratio (actually, minus the ratio) is shown in Fig. 1 for a group of 20 mtorr discharges with peak I_ϕ between 300 and 500 kA. The abscissa is F/θ (at peak θ). The first significant feature is that all (but one) of the discharges have negative ratio $\dot{B}_\parallel^{(1)}/\dot{B}_\perp^{(1)}$. It can be shown by simple arguments that this is a property which would be expected of magnetic fluctuations arising from $\vec{k} \cdot \vec{B} = 0$ singular layers in the pinch. That is, the experimental polarization is consistent with resonant ($\vec{k} \cdot \vec{B} = 0$) phenomena, whereas the opposite polarization (i.e., positive $\dot{B}_\parallel^{(1)}/\dot{B}_\perp^{(1)}$) would not be consistent.

The second significant feature of the data in Fig. 1 is the trend toward more parallel fluctuations at deeper reversal (leftward on abscissa). To investigate this, we have considered the effect of a single singular layer mode for the case of a Bessel function equilibrium. The mode has wavevector $\vec{k} (\equiv k_\phi \hat{\phi} + \frac{m}{r} \hat{\theta})$ such that $\vec{k} \cdot \vec{B} = 0$ at $r = r^*$. The computed polarization ratios for a single mode (in the Bessel function equilibrium model) are shown in Fig. 2 for three singular layer locations r^*. Comparison with Fig. 1 shows that the experimental data would be consistent with singular layers ($\vec{k} \cdot \vec{B} = 0$) in the outer half of the pinch, i.e.,

$$\frac{1}{2} r_w < r^*_{exp} < r_w \quad .$$

LOCATION OF ELECTRON DENSITY FLUCTUATIONS

The chord-averaged electron density is measured simultaneously along seven vertical paths, shown in Fig. 3. The data can be differentiated in time to give $\dot{n}_e$ along each chord. The root-mean-square values (in time) of these chord-averaged $\dot{n}_e$'s give an indication of the spatial distribution (in offset major radius, $R - R_0$) of the fluctuations. Figure 4 shows such data averaged over 30 identical stabilized pinch discharges at 20 mtorr (D_2) and $I \approx 400$ kA. The 100 μs averaging period is centered around peak current, at which time the toroidal field at the wall is (positive) 1 kG. The chord-averaged fluctuations are

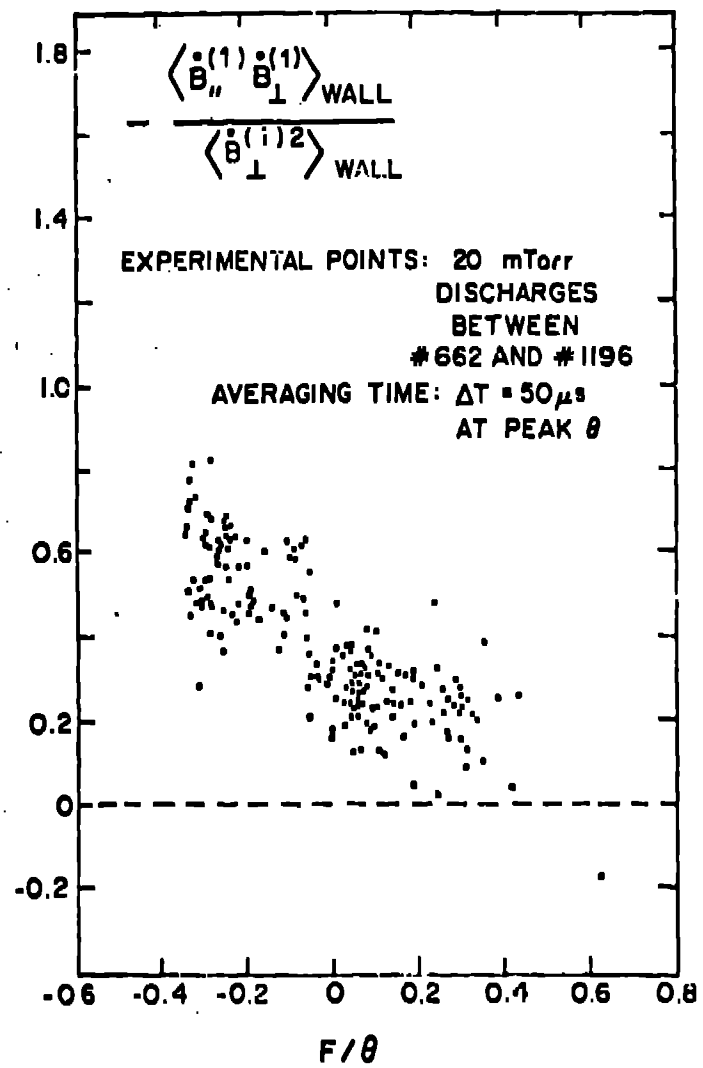

Fig. 1
Experimental polarization ratios as a fluctuating mode for the case of function of F/θ (= B_ϕ/B_θ at wall). Each data point is a separate discharge, during 50 μs centered around peak θ.

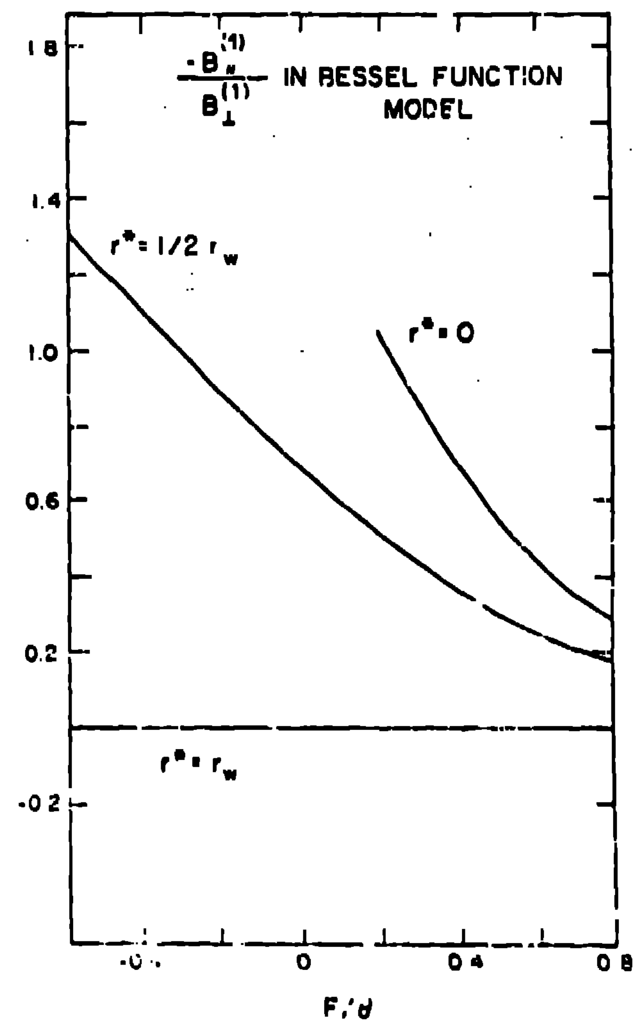

Fig. 2
Polarization ratios for a single Bessel function equilibrium.

peaked toward the outside; dn/dr is twice as large at $R - R_0 = 16.4$ cm as at $R - R_0 = 0.5$ cm. The density profiles (not shown), on the other hand, do not peak at the edge, but are, instead, flat to within 10%. Thus, the fluctuation level in terms of $\delta n/n$ is probably higher toward the edge. If the fluctuations are isotropic, the profile of average $\dot{n}_e$ in Fig. 4 would Abel transform into a profile even more strongly edge-peaked in minor radius. However, the isotropy

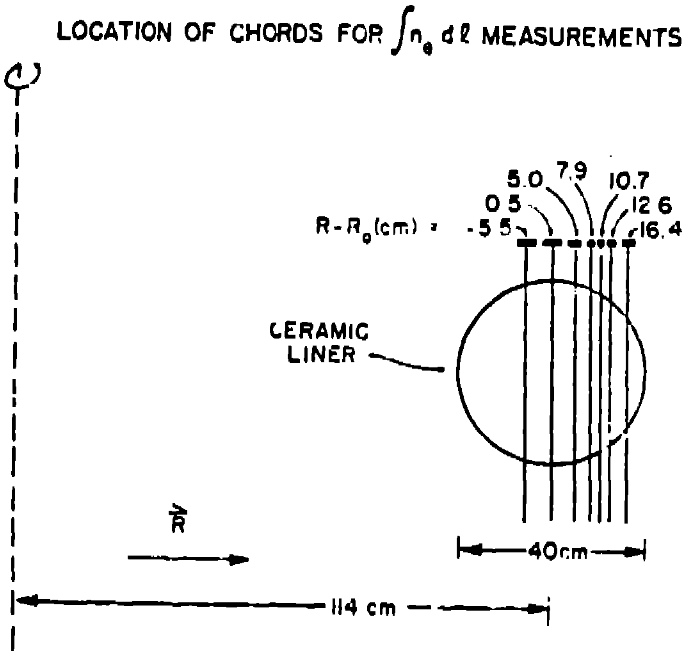

Fig. 3
Arrangement of the 3.39 μm interferometer chords for electron density measurements.

of the fluctuations is unknown, so Abel inversion of the major radius profiles would not be strictly justified.

The same shot-, chord-, and time-averaged data are shown in Fig. 5 for 14 self-reversing pinch discharges at 5 mtorr (D_2). The edge-to-center fluctuation ratio is now about 3. The (hollow) density profiles (not shown) are only about half as edge-peaked; thus the fluctuation level $\delta n/n$ is again probably higher toward the edge.

CONCLUSIONS

External measurements of magnetic fluctuations indicate consistency with $\vec{k} \cdot \vec{B} = 0$ singular layer effects. Comparison with a Bessel function equilibrium implies that the $\vec{k} \cdot \vec{B} = 0$ layers would lie in the outer half of the pinch.

Chord-averaged density measurements indicate edge-peaking of the density fluctuations. The criteria for valid Abel inversion are not met; nonetheless, the profiles (in major radius) of chord-averaged $\dot{n}_e$ are consistent with the density fluctuations being peaked on the outside in minor radius.

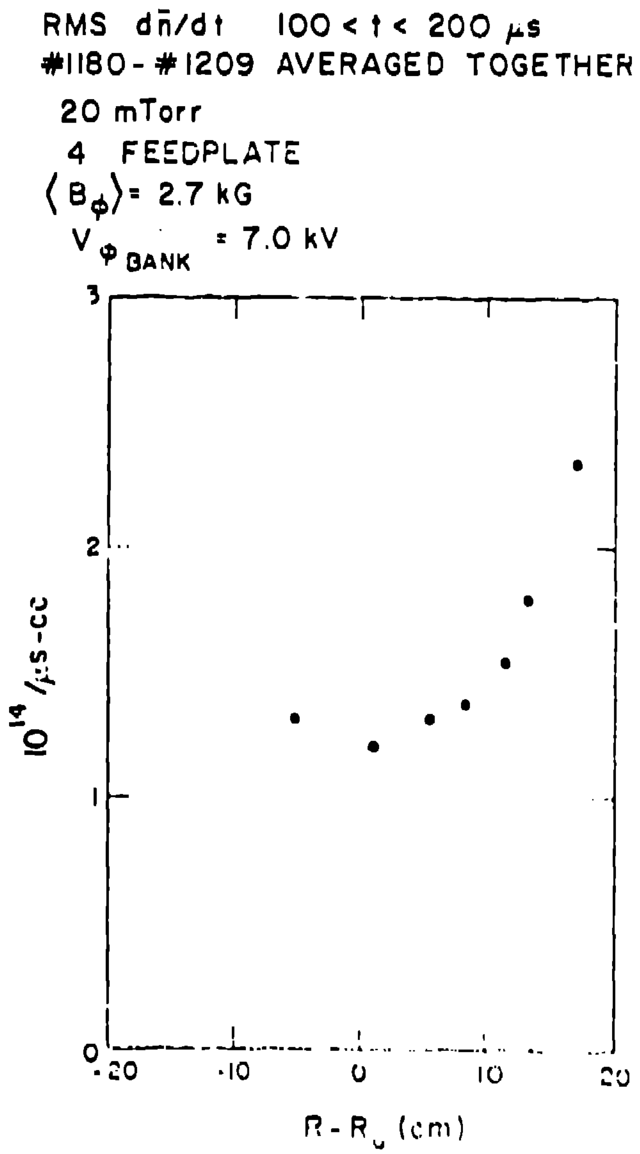

Fig. 4
Chord-, shot-, and time-averaged $\dot{n}_e$ as a function of offset major radius for thirty identical stabilized pinch discharges.

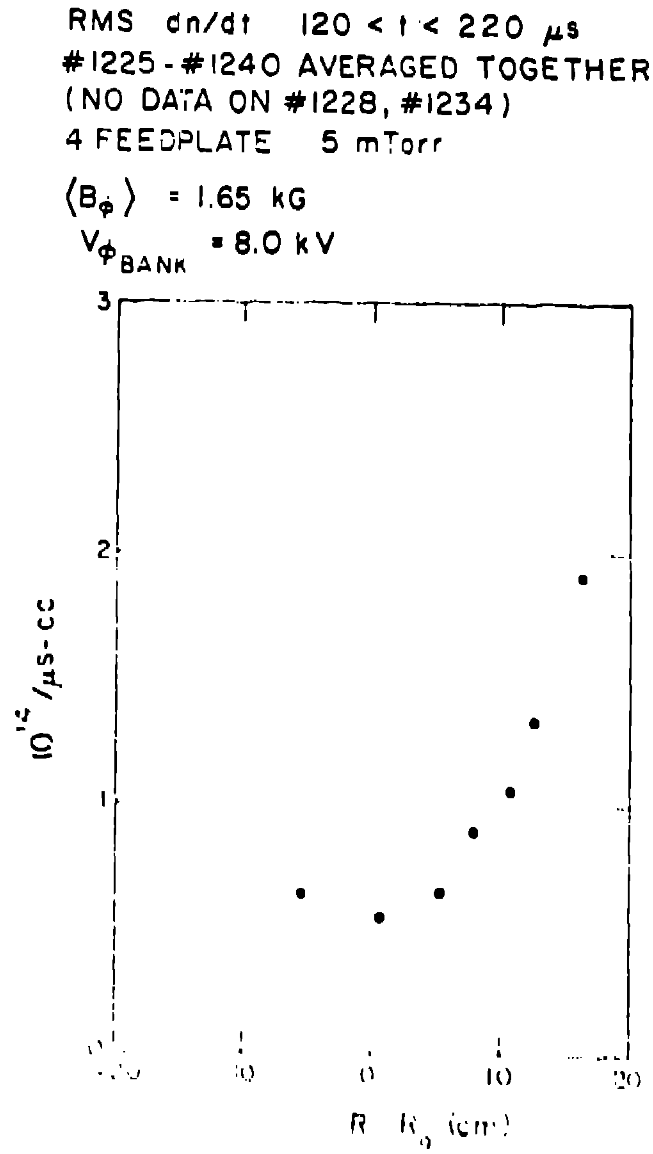

Fig. 5
Chord-, shot-, and time-averaged $\dot{n}_e$ as a function of offset major radius for fourteen identical self-reversing discharges.